

Topology Enabled Unconventional Superconductivity in a Time-Reversal Symmetry Breaking Bulk Superconductor

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To Great People



synthesis and
characterization

Jackson Badger
Yunshu Shi
Davis Zackaria
Henry Bowman
Kelly Neubauer
Peter Klavins

ARPES

Matthew Staab
Antonio Rossi
Inna Vishik

NMR-NQR

Phurba Sherpa
Igor Vinograd
Nick Curro

electronic structure
calculations

Yundi Quan
Warren Pickett



Jim Fettinger
Kasey Devlin
Susan Kauzlarich



Phurba Sherpa
Michihiro Hirata
Filip Ronning
Sean Thomas



Myong-Chul Jung
Antia Botana



Jorge Quintanilla



Dai Aoki



Shuntaro Sumita



Yanan Zhang
Huiqiu Yuan



Jeff Sonier

PAUL SCHERRER INSTITUT



Toni Shiroka



Gianrico Lamura



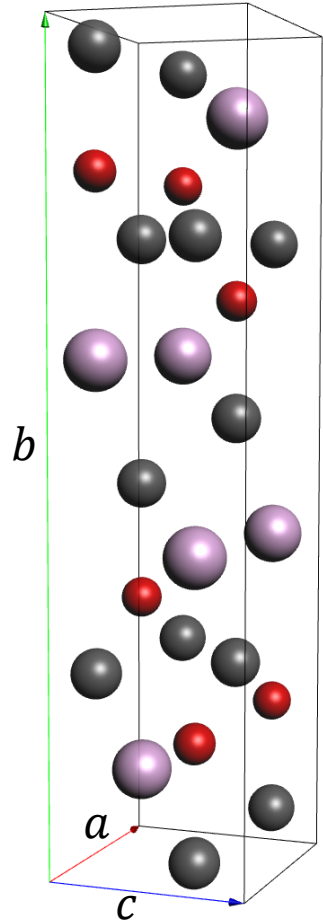
Makariy Tanatar
Ruslan Prozorov



Beena Kalisky

UC NATIONAL LABORATORY FEES
RESEARCH PROGRAM

Introduction to LaNiGa₂

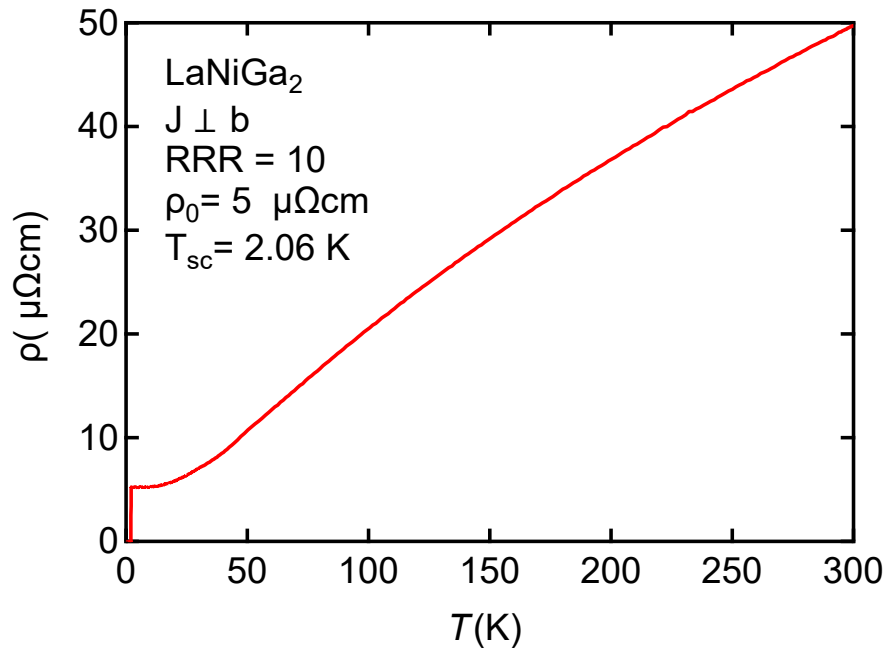


$Cmcm$ (#63)

$$a = 4.2808(6) \text{ \AA}$$

$$b = 17.466(2) \text{ \AA}$$

$$c = 4.2578(6) \text{ \AA}$$

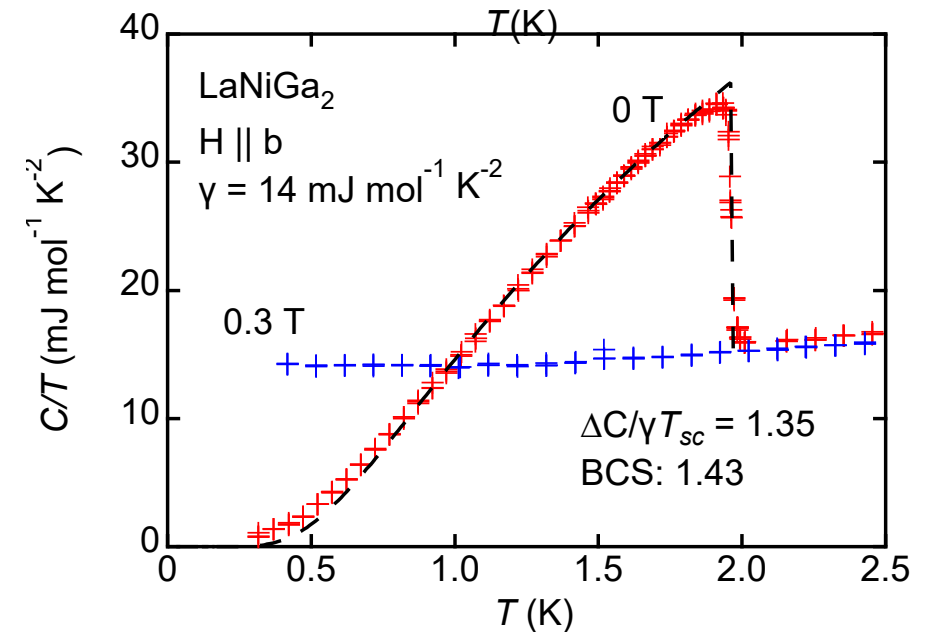
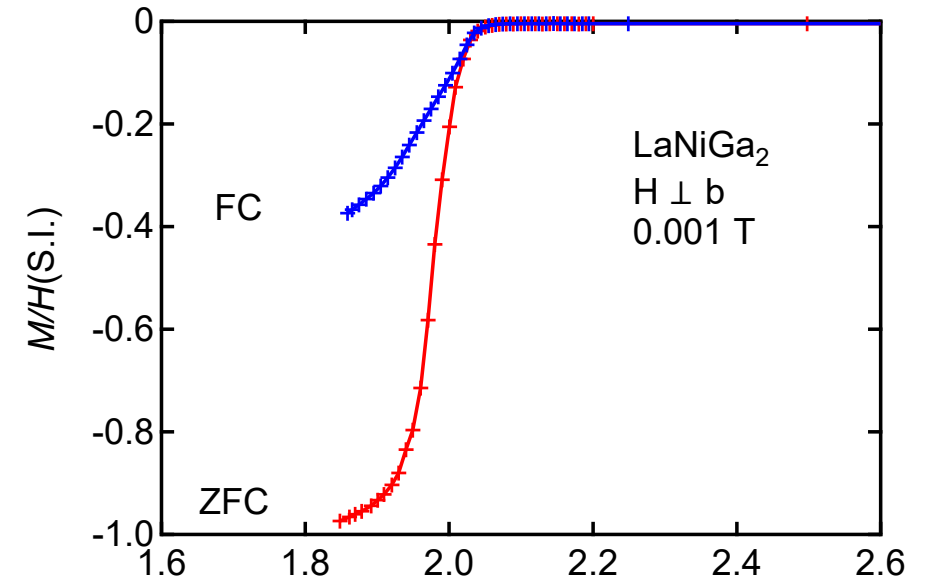


see also:

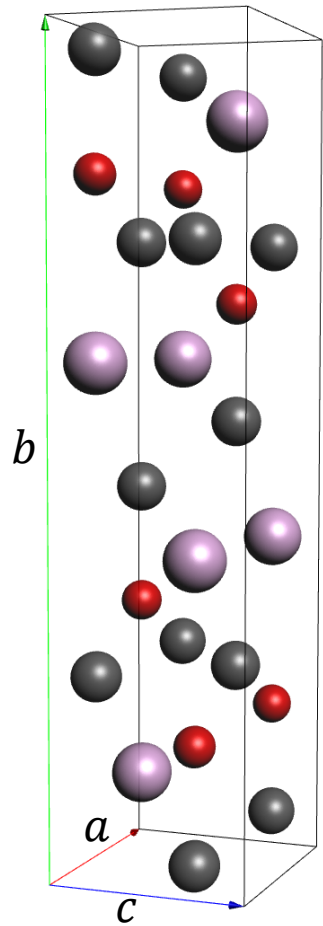
Y. Aoki *et al.* J. Phys. Soc. Jpn. **64** 3986 (1995)

N.L. Zheng *et al.* Phys. Rev. B **66** 092503 (2002)

- weak coupling
- fully gapped
- not strongly correlated



Introduction to LaNiGa_2

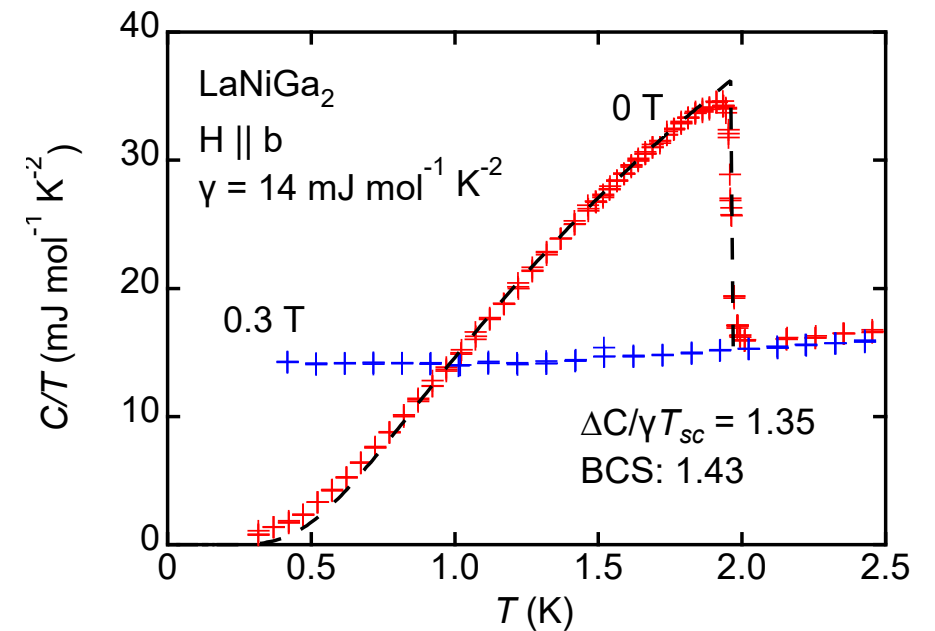
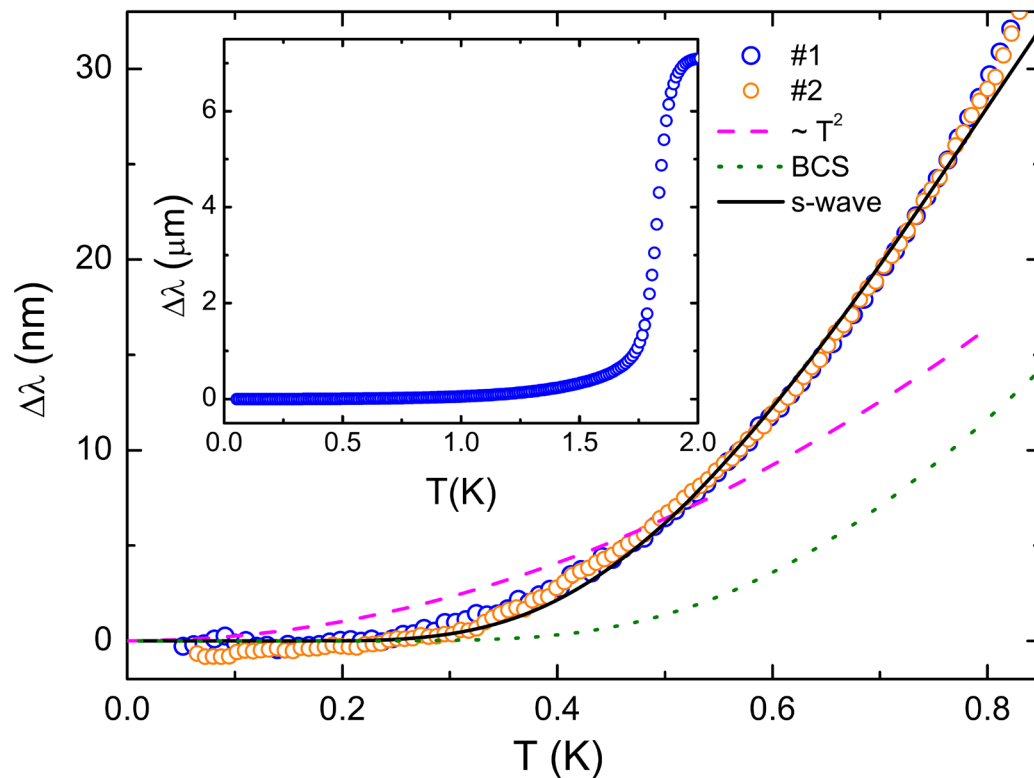


$Cmcm$ (#63)

$$a = 4.2808(6) \text{ \AA}$$

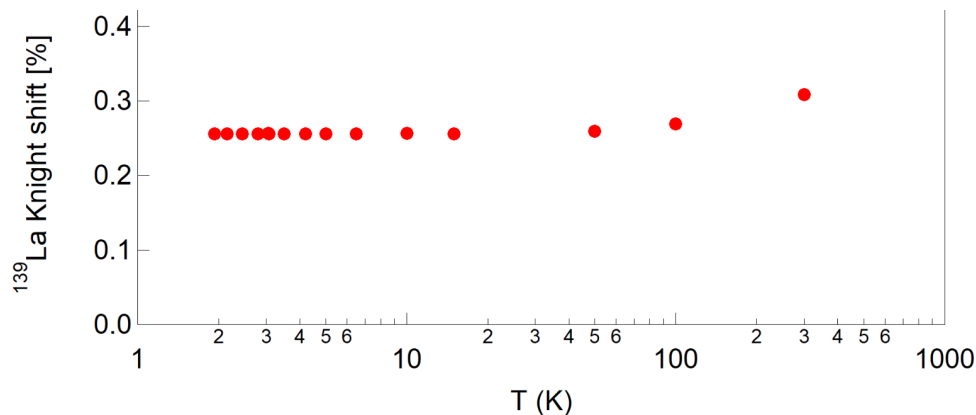
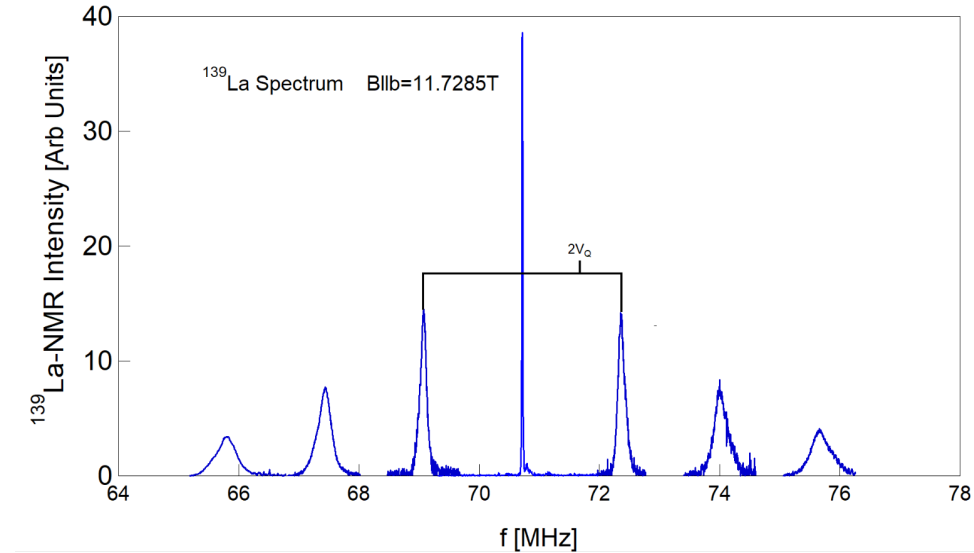
$$b = 17.466(2) \text{ \AA}$$

$$c = 4.2578(6) \text{ \AA}$$



Introduction to LaNiGa₂: no magnetic correlations

LaNiGa₂ NMR

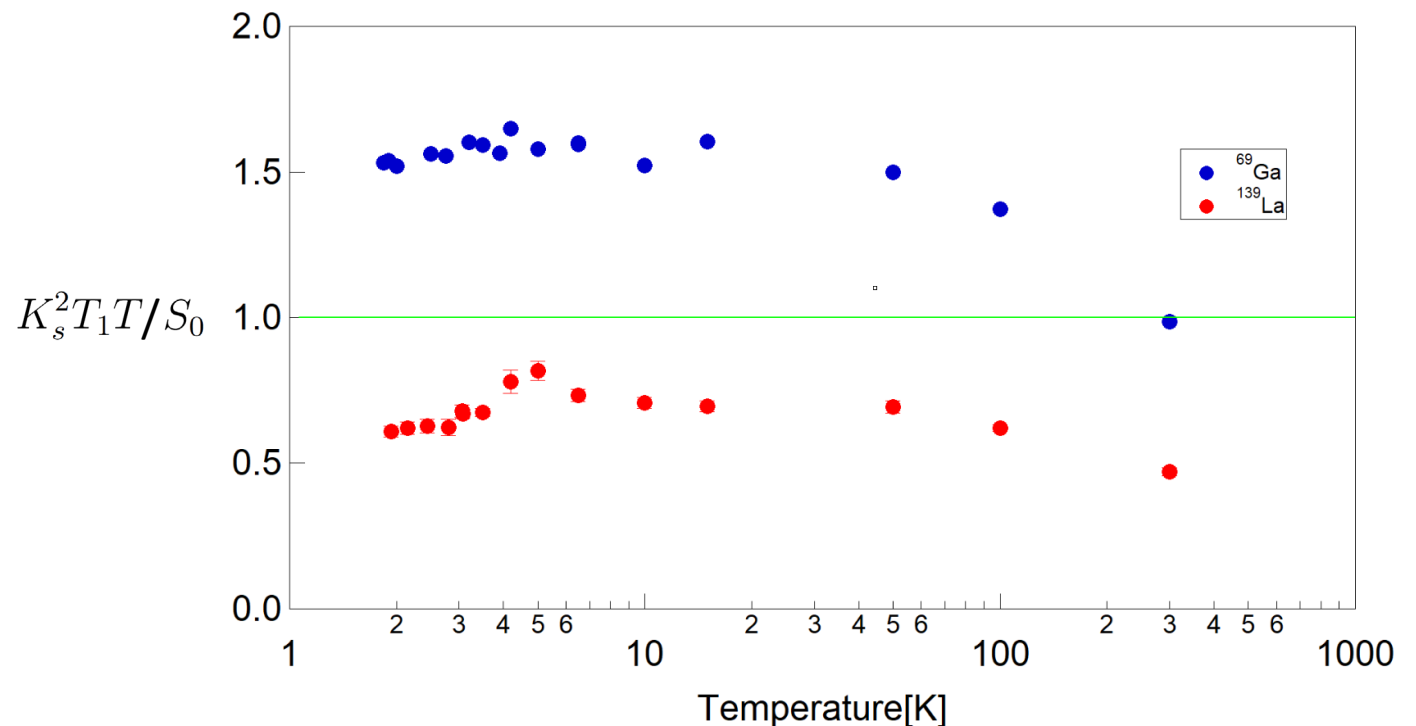


NMR in normal state: no magnetic correlations
NMR in superconducting state: in progress

LaNiGa₂: conventional superconductor?

- one sharp and complete superconducting transition
- fully gapped (no superconducting gap nodes)
- centro-symmetric orthorhombic structure
- no evidence for magnetic correlations

$$\text{Korringa ratio: } \frac{\hbar}{4\pi k_B} \left(\frac{\gamma_e}{\gamma_n} \right)^2 = S_0$$



Introduction to LaNiGa₂: time-reversal symmetry breaking

UPt₃
URu₂Si₂
UTe₂
Sr₂RuO₄
Ba_{1-x}K_xFe₂As₂
Pr(Os_{1-x}Ru_x)₄Sb₁₂
StPtAs
(Lu,Y,Sc)₅Rh₆Sn₁₈

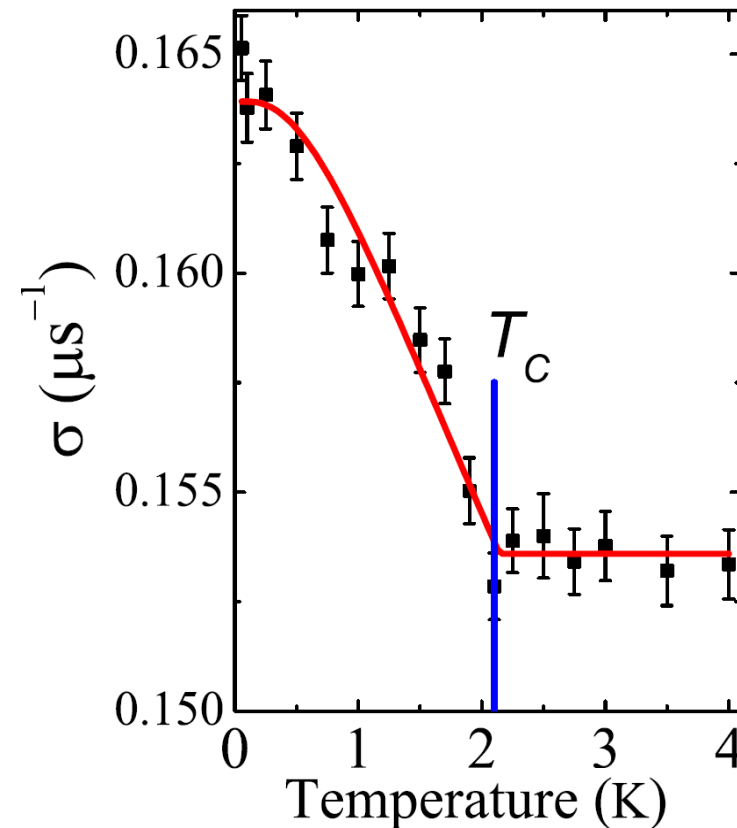
complex multicomponent

UPt₃
UTe₂
Pr_{1-y}La_yPt₄Ge₁₂

nodal triplet

CaPtAs
Re_{0.82}Nb_{0.18}
Re₆(Zr,Hf,Ti)
LaNiC₂
La₇(Ir,Rh)₃
Zr₃Ir
K₂Cr₃As₃
(Nb,Ta)RuSi

non-centrosymmetric



A. D. Hillier *et al.* Phys. Rev. Lett. **109** 097001 (2012)

S. K. Ghosh *et al.* J. Phys.: Condens. Matter **33** 033001 (2021)

$$B_{int} = 0.02 \text{ mT}$$

Introduction to LaNiGa₂: time-reversal symmetry breaking

LaNiGa₂

topological crystalline
superconductor

UPt₃
URu₂Si₂
UTe₂
Sr₂RuO₄
Ba_{1-x}K_xFe₂As₂
Pr(Os_{1-x}Ru_x)₄Sb₁₂
StPtAs
(Lu,Y,Sc)₅Rh₆Sn₁₈

complex multicomponent

~~LaNiGa₂~~

- one sharp and complete superconducting transition
- fully gapped (no superconducting gap nodes)
- centro-symmetric orthorhombic structure
- no evidence for magnetic correlations
- non-symmorphic structure

UPt₃
UTe₂
Pr_{1-y}La_yPt₄Ge₁₂

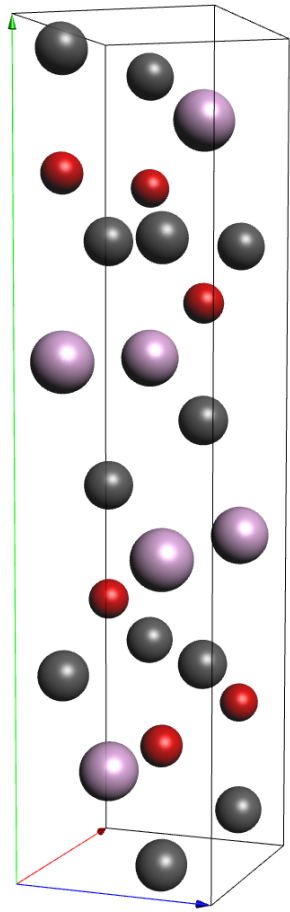
nodal triplet
~~LaNiGa₂~~

CaPtAs
Re_{0.82}Nb_{0.18}
Re₆(Zr,Hf,Ti)
LaNiC₂
La₇(Ir,Rh)₃
Zr₃Ir
K₂Cr₃As₃
(Nb,Ta)RuSi

non-centrosymmetric

~~LaNiGa₂~~

Introduction to LaNiGa_2 : crystal structure



$Cmcm$ (#63)

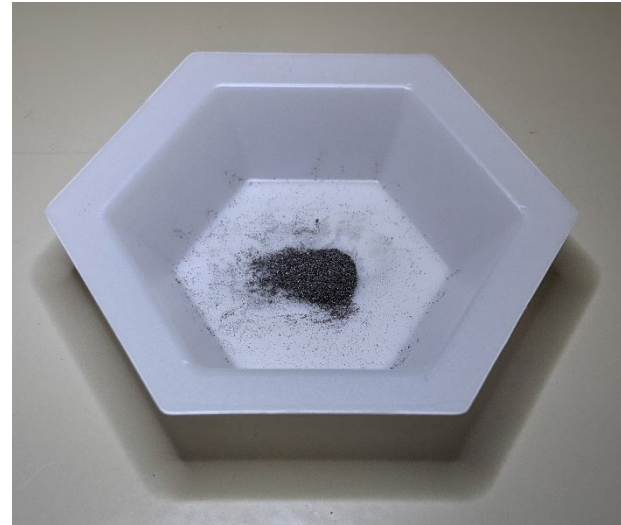
$$a = 4.2808(6) \text{ \AA}$$

$$b = 17.466(2) \text{ \AA}$$

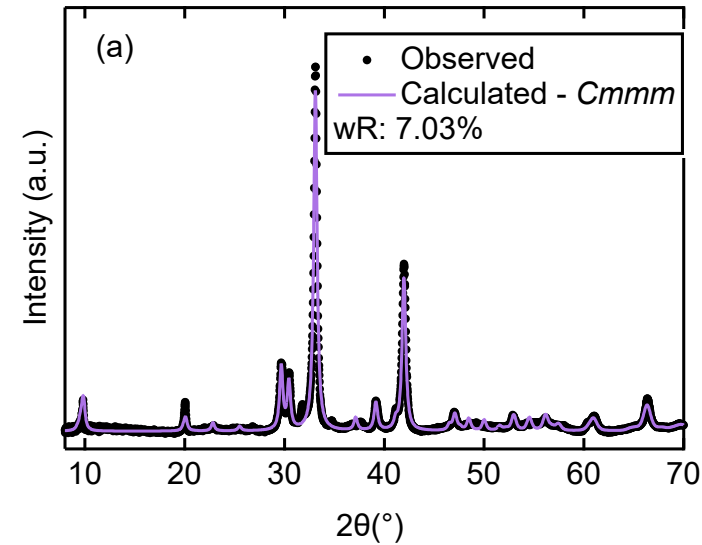
$$c = 4.2578(6) \text{ \AA}$$

previous reports:

polycrystals



powder x-ray diffraction



$Cmcm$ (#65)

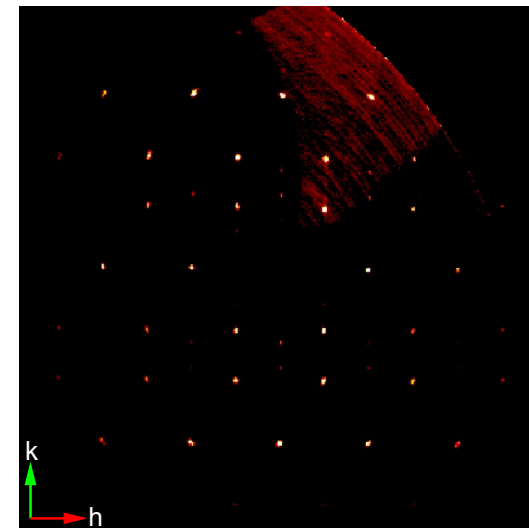
mirror
(symmorphic)

our study:

single crystals



single crystal x-ray diffraction

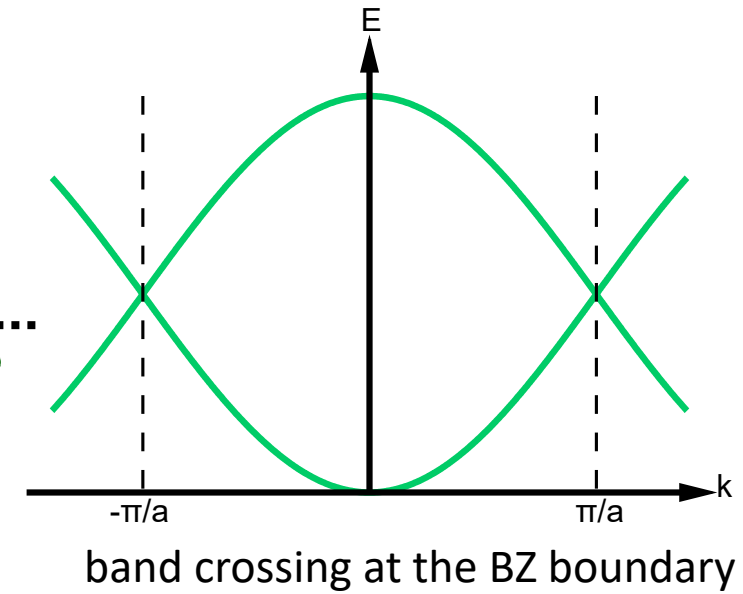
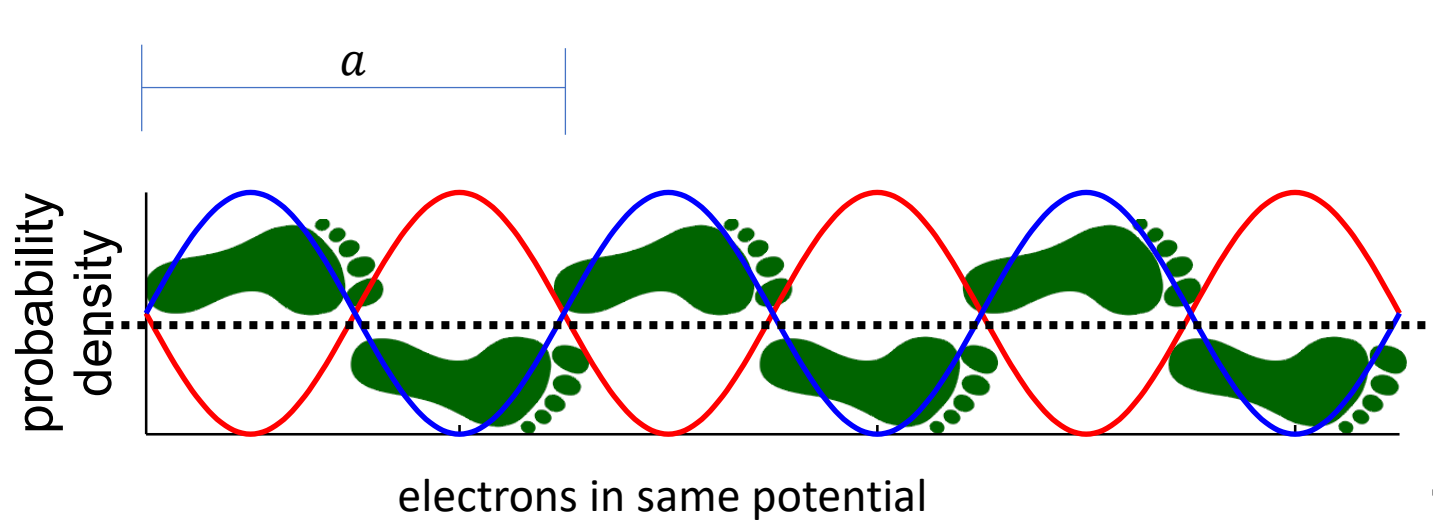


$Cmcm$ (#63)

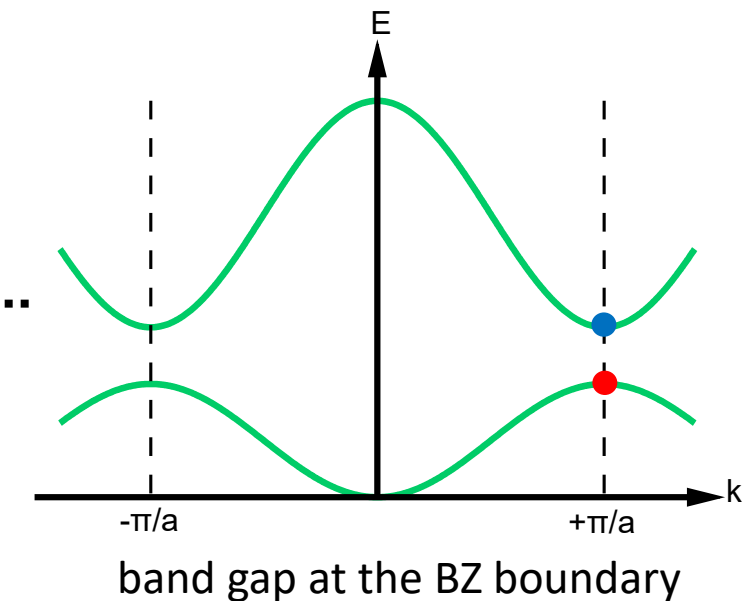
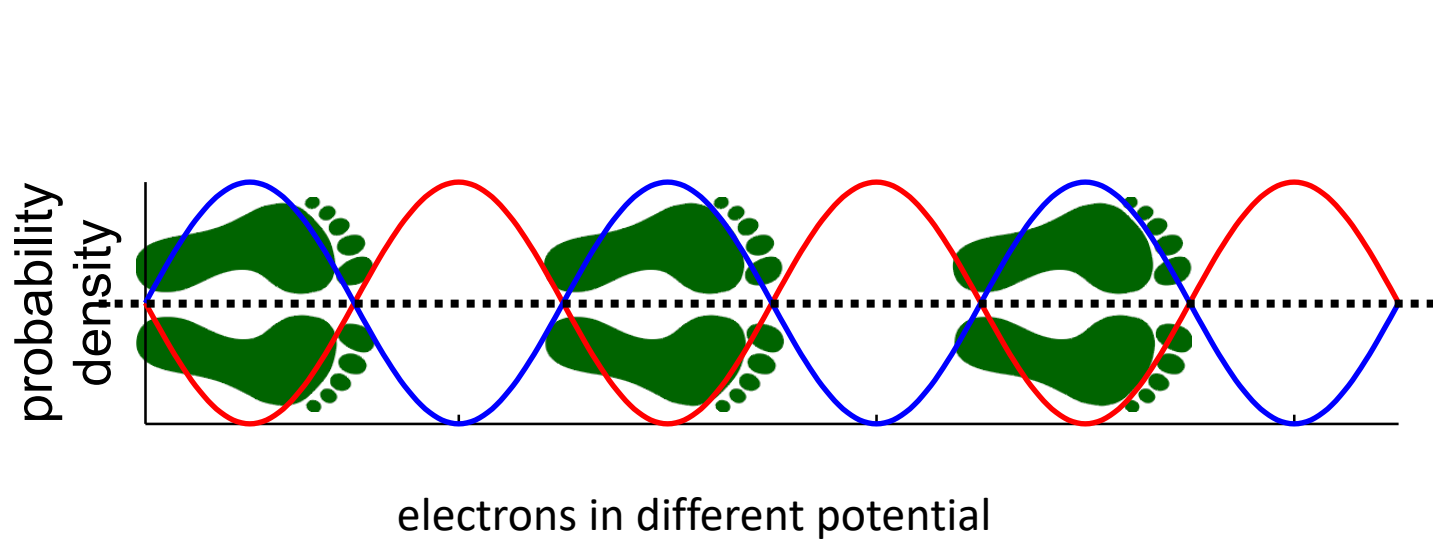
glide along c
(non-symmorphic)

Non-Symmorphic Symmetry and Band Degeneracy

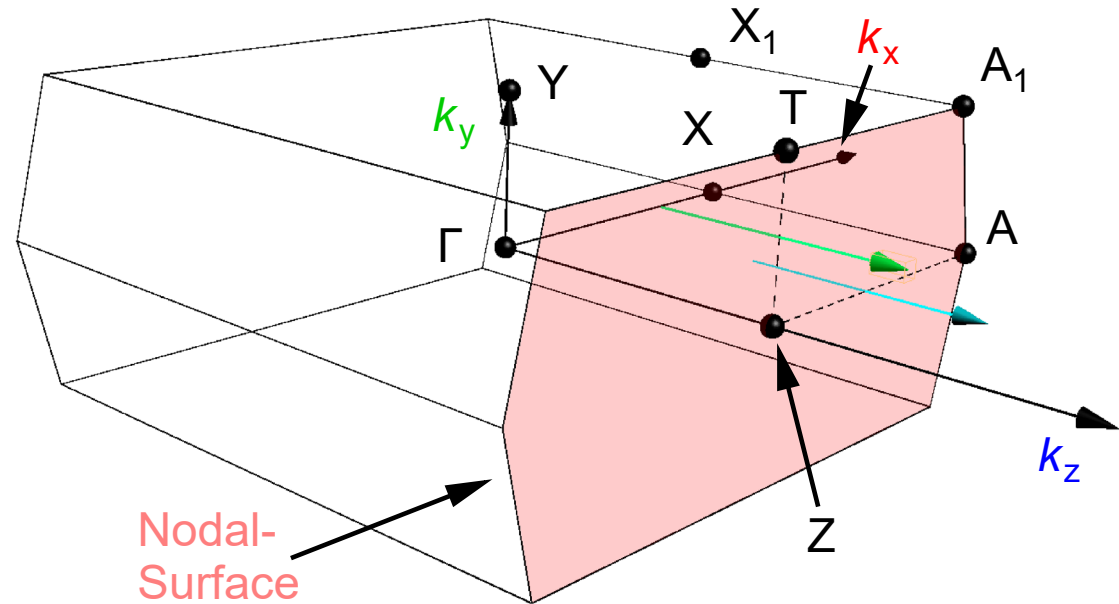
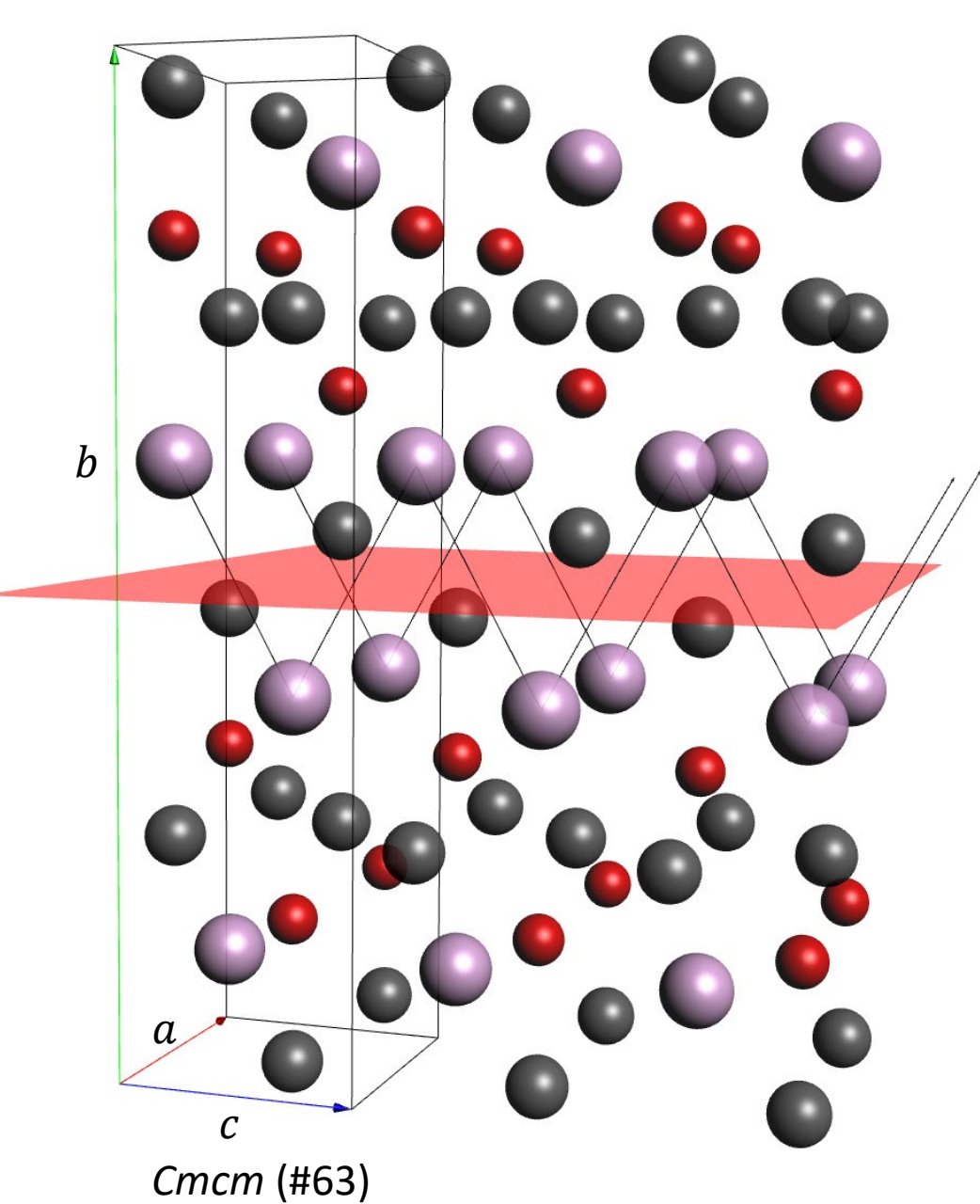
non-symmorphic
glide symmetry



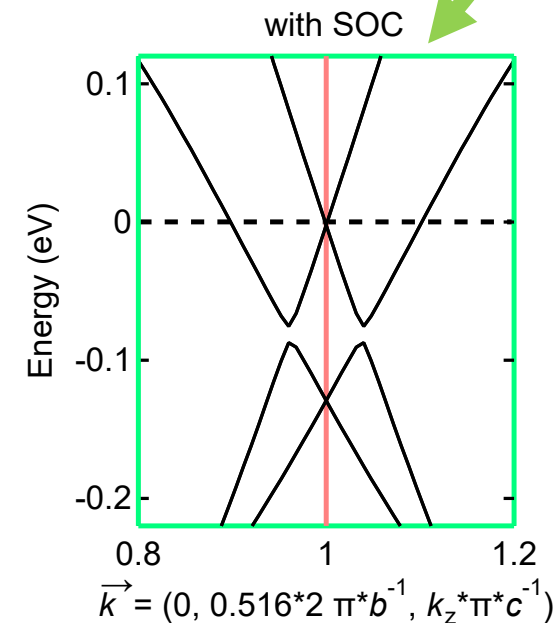
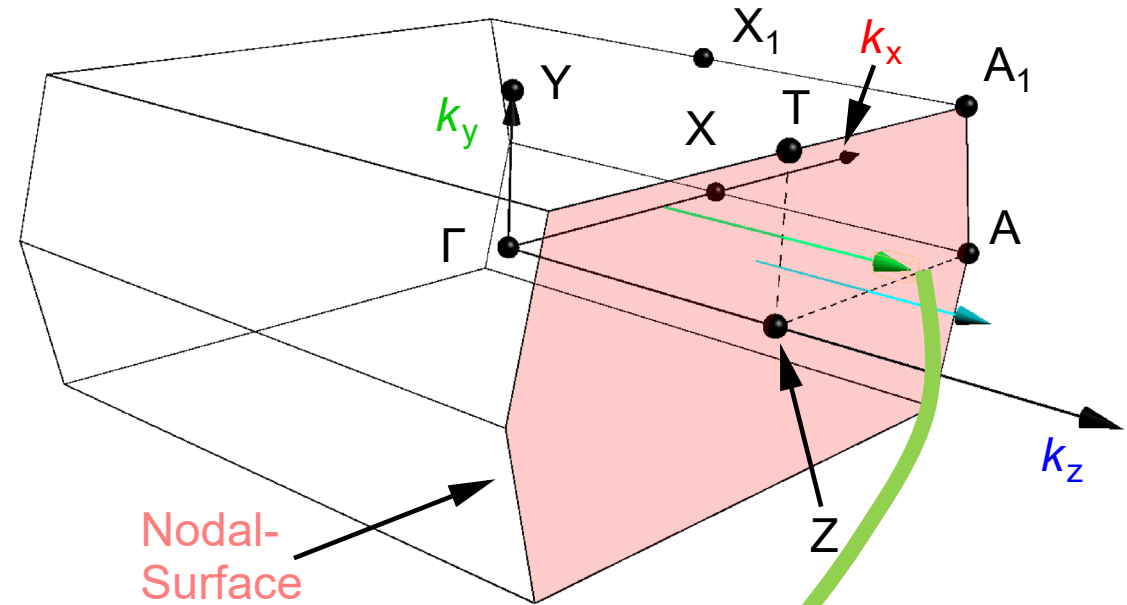
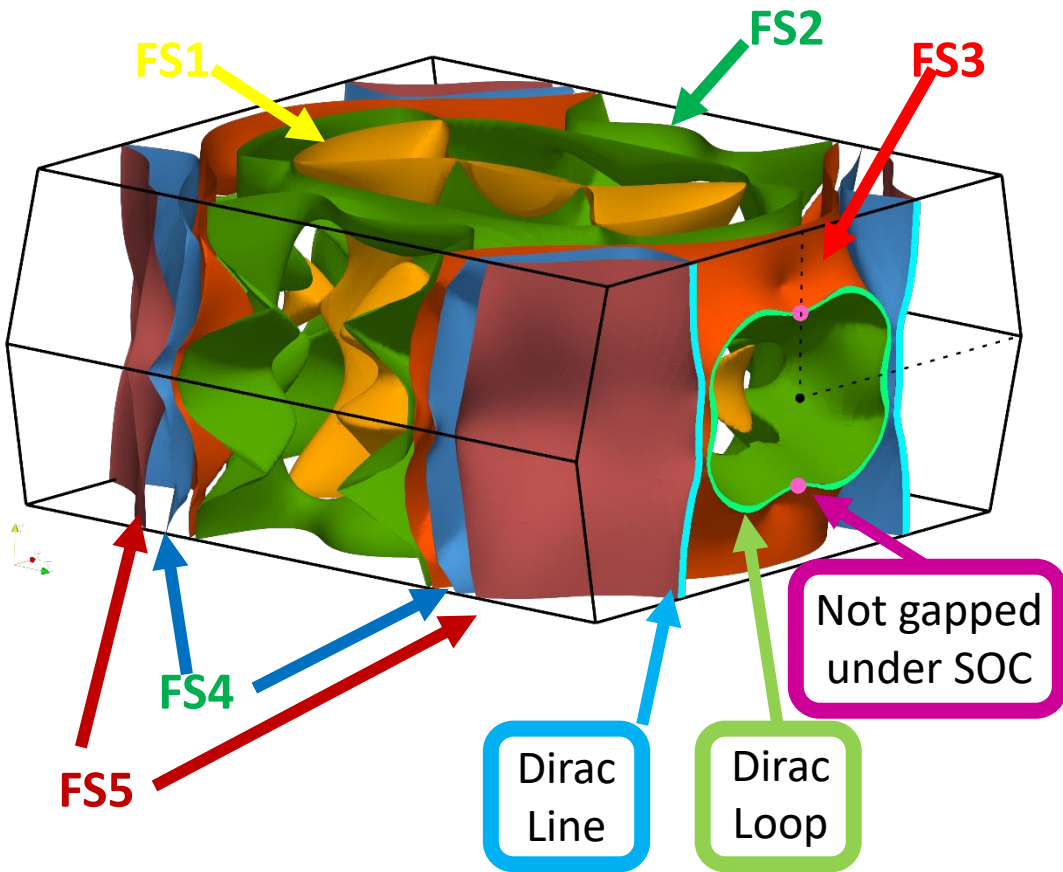
symmorphic
mirror symmetry



Dirac line and Dirac loop in LaNiGa_2

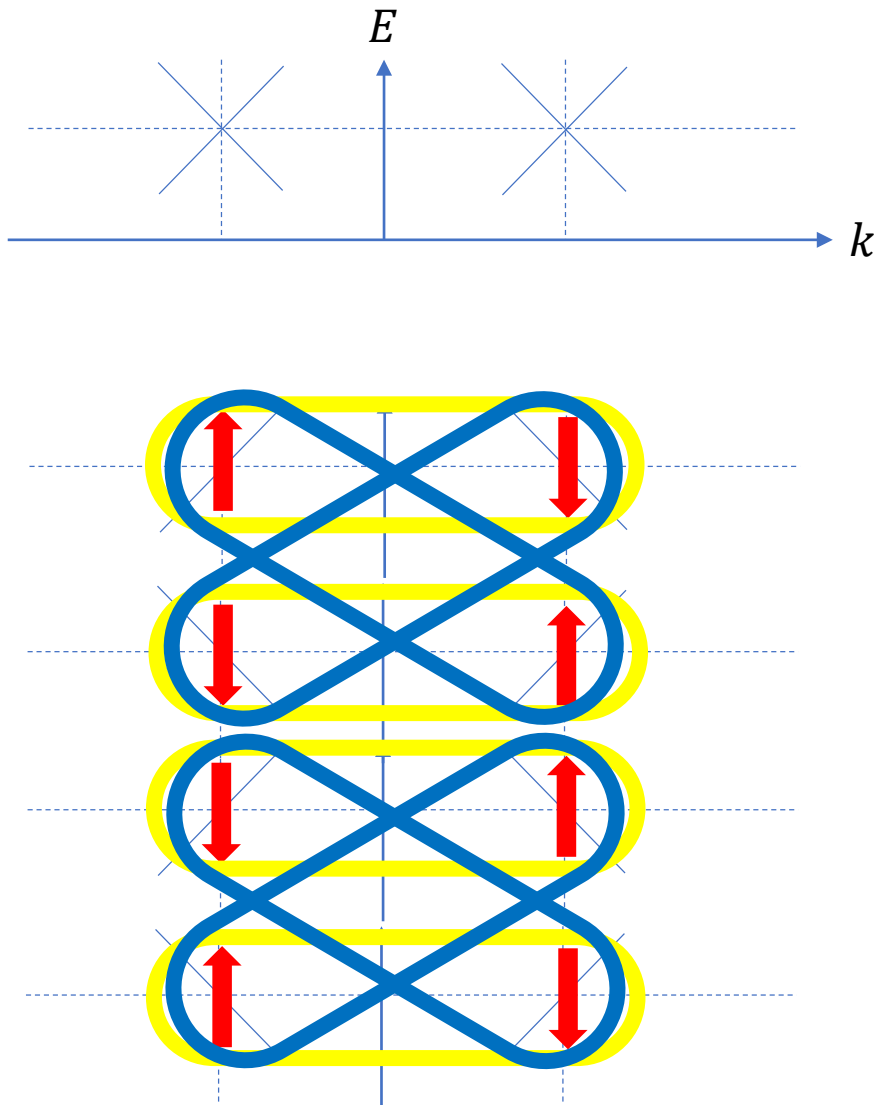


Dirac line and Dirac loop in LaNiGa_2



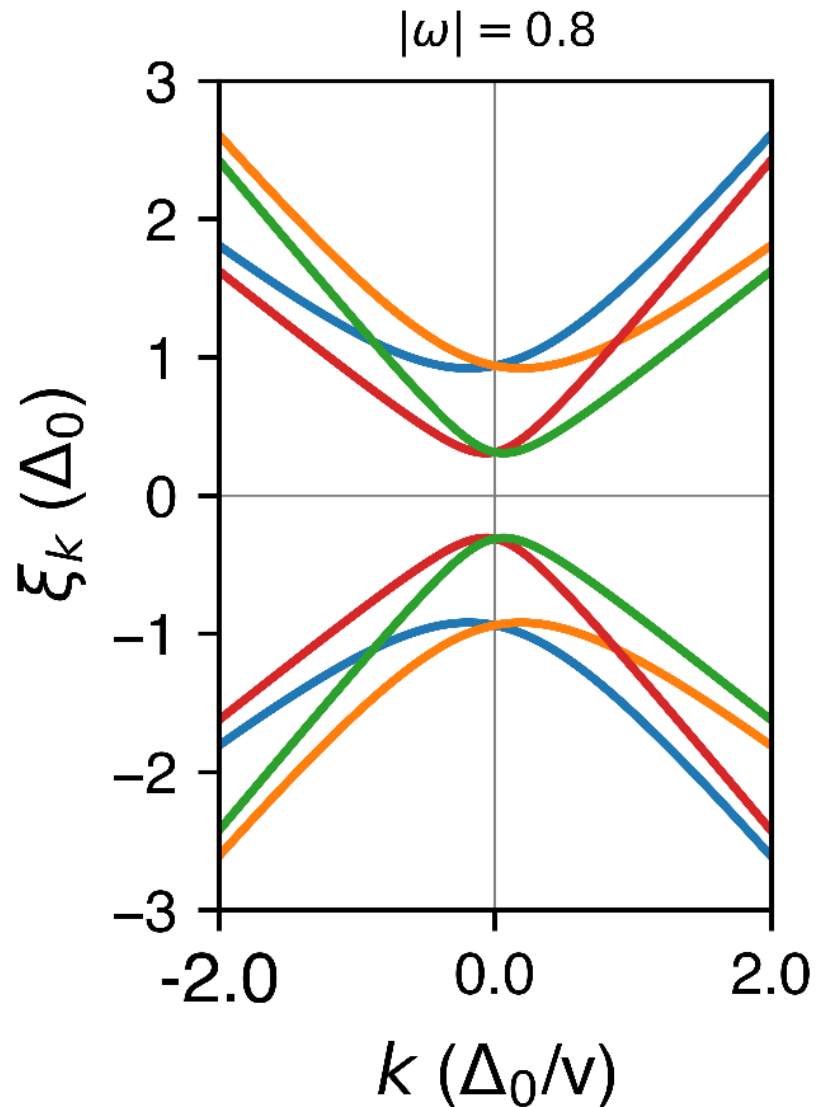
- Dirac line and Dirac loop
- at E_F
- 2 points not gapped under SOC

Fully gapped spin-triplet superconductivity



band (sublattice, inter-orbital, inter-layer, inter-valley)	orbital	spin	total
symmetric	symmetric (s-wave, d-wave)	antisymmetric (singlet)	antisymmetric
symmetric	antisymmetric (p-wave, f-wave)	symmetric (triplet)	antisymmetric
antisymmetric	symmetric (s-wave, d-wave)	symmetric (triplet)	antisymmetric
antisymmetric	antisymmetric (p-wave, f-wave)	antisymmetric (singlet)	antisymmetric

Topology of the BdG spectrum



model modified from Ghosh et al. Phys. Rev. B **101** 100506 (2020)
added linear dispersion

non-unitary triplet pairing potential:

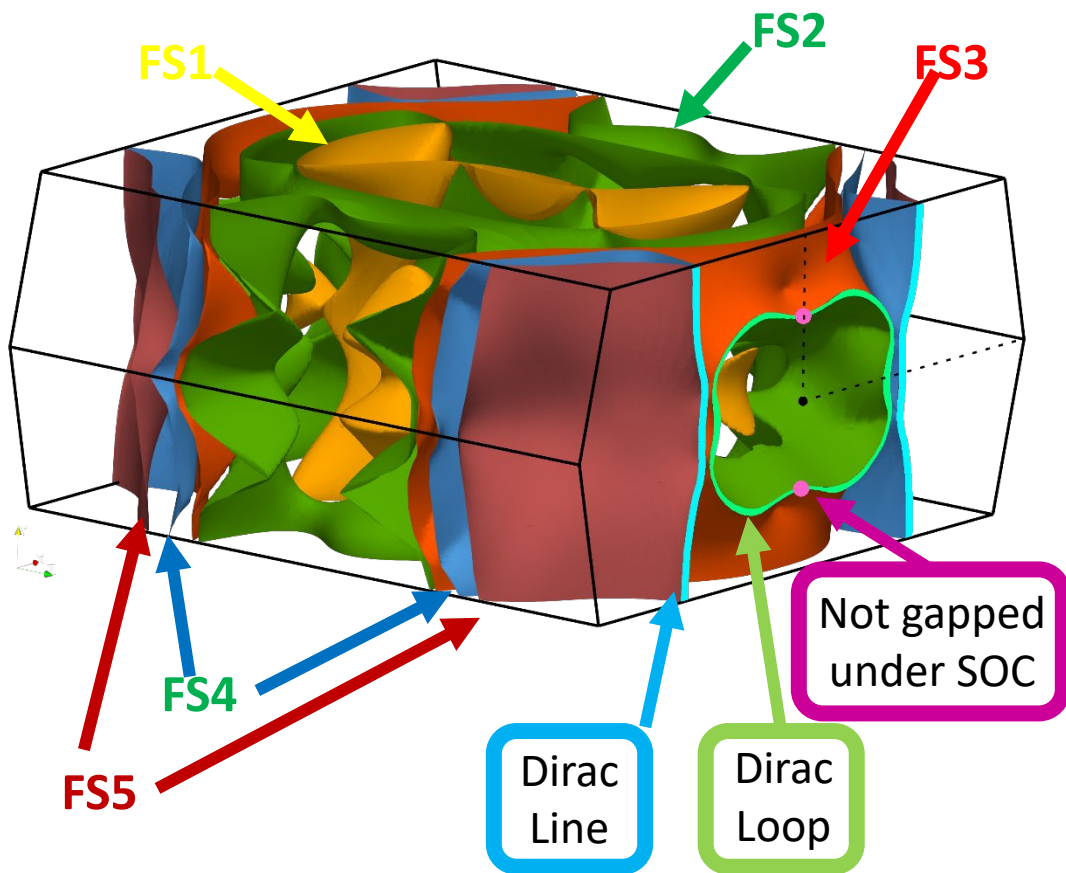
$$\hat{\Delta} = i(\Delta_o \tilde{\eta} \cdot \tilde{\sigma}) \sigma_y \otimes i\tau_y$$

linear dispersion

$$\epsilon_k = \pm \left[\sqrt{\{vk_{\perp} - \mu\}^2 + |\Delta_o|^2(1 \pm |\vec{\omega}|)} \pm \beta k_{\perp} \right]$$

crossings at the Brillouin zone boundary: the degeneracy is retained even in the BdG spectrum

Conclusions



- method to synthesize single crystals
- single crystals indicate a non-symmorphic space group
- LaNiGa_2 is a topological crystalline metal due to non-symmorphic symmetries
- Dirac line and Dirac loop at the Fermi energy
- 2 true Dirac points (not gapped under SOC)
- topology enables fully gapped spin-triplet superconductivity
- other non-symmorphic superconductors need to be reinvestigated for time-reversal symmetry breaking

~~look for new superconductors~~

look for known superconductors

with non-symmorphic structure
band crossing at E_F can be calculated (DFT)